VŠB –Technical University of Ostrava

Faculty of Mechanical Engineering

Department of Power Engineering

Increasing of Biodegradeble Materials Heating Value

Zvýšení výhřevnosti biodegradabilních materiálů

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VŠB - Technical University of Ostrava
Faculty of Mechanical Engineering
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Diploma Thesis Assignment

Student:	**Gizemsu Kaya, BSc**
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The thesis language:	English

Description:

Re-search of the use of suitable biodegradable materials.
Possibilities to increase the calorific value of the biodegradable material and processing of the selected method.
Implementation of a specific solution including calculations.
The work will contain the drawings documentation.
Propose the solution for laboratory conditions with an assessment of subsequent applicability.

References:

1. KALOGIROU, Efstratios N. Waste-to-Energy Technologies and Global Applications. Boca Raton, FL: CRC Press, p. 244, 2018. ISBN 978-1-138-03520-1.
2. HUNG, Yung-Tse, Lawrence K WANG a Nazih K SHAMMAS. Handbook of Environment and Waste Management. Air and Water Pollution Control. New Jersey: World Scientific,p. 1227, 2014. ISBN 978-981-4327-69-5.
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4. KREITH, Frank a George TCHOBANOGLOUS. Handbook of Solid Waste Management. 2nd ed. New York: McGraw-Hill, 2002. ISBN 0-07-135623-1.
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Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

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Annotation of Diploma Thesis

KAYA, G. *Increasing of Biodegradable Material's Heating Value: Diploma Thesis.* Ostrava: VŠB –Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Power Engineering, 2019, 56 p. Thesis head: Sassmanova, V.

The diploma thesis is explaining drying methods for increasing the heating value of biodegradable materials. The research based on literature examines the potential effects of biodegradable materials through waste management process. It includes theoretical and experimental information about solar drying and oven drying systems. Based on these information, it shows the fundamental differences between methods in question and makes suggestions to have more efficient results from them.

Key words: biodegradable, heating value, solar drying method, oven drying method, waste management

Abstrakt CZ

KAYA, G. *Zvýšení topné hodnoty biologicky rozložitelného materiálu: diplomová práce.* Ostrava: Vysoká škola báňská - Technická univerzita Ostrava, Fakulta strojní, Katedra energetiky, 2019, 56 p. Thesis head: Sassmanova, V.

Diplomová práce vysvětluje metody sušení pro zvýšení výhřevnosti biologicky rozložitelných materiálů. Výzkum založený na literatuře zkoumá možné účinky biologicky rozložitelných materiálů prostřednictvím procesu nakládání s odpady. Zahrnuje teoretické a experimentální informace o solárním sušení a sušicích systémech. Na základě těchto informací ukazuje základní rozdíly mezi danými metodami a předkládá návrhy na jejich efektivnější výsledky.

Klíčová slova: biologicky rozložitelný, výhřevnost, metoda solárního sušení,metoda sušení v peci, nakládání s odpady

Table of Contents

List of used signs and symbols

m_w	Mass of water evaporated	[kg]
V_a	Volume of air needed to evaporate moisture	[m^3]
$\dot{V}$	Volume air flow rate	[m^3 /h]
h_c	Collector system efficiency	[%]
h_p	Drying efficiency	[%]
R_a	Specific gas constant	[J/kg.K]
P_a	Partial pressure of air in atmosphere	[Pa]
c_{pa}	Specific heat capacity of air	[J/kg.K]
L_t	Latent heat of vaporization of water	[KJ/ K]
T_f	Temperature of air leaving dryer	[K]
T_o	Temperature of leaving collector	[K]
T_a	Ambient air temperature	[K]
I	Mean solar radiation incident on collectors	[W/m^2]
A_c	Total surface area of collectors	[m^2]
P_f	Power used to operate fan	[W]
ΔQ	Heat output rate difference	[K/h]
Q_{in}	Cold air heat output rate	[KJ/h]
Q_{out}	Warm air heat output rate	[KJ/h]
ρ	Air density	[kg /m^3]
t_1	Average temperature at the inlet of the drying chamber	[K]
t_2	Maximum air temperature in the dryer chamber	[K]
$LHV_{initial}$	Initial lower heating values	[MJ/kg]

LHV_{final}	Final lower heating values	[MJ/kg]
W_i	Initial weight of a waste component	[kg]
W_j	Final weight of a waste component	[kg]
Mc_i	Initial moisture content of the waste component	[%]
Mc_j	Final moisture content of the waste component	[%]
E_i	Energy content of a waste component	[MJ/kg]

1. Introduction

Waste is a worldwide issue that has significant effects on living beings and environment. By the increase of population, the produced waste is obtaining a higher amount in time. Each year 3 billion tons waste is generated in Europe. This includes total amount of municipal, industrial and constructional wastes. One of the major source of this problem is that many producers focus to increase benefits by producing one-time use products without considering the importance of reuse, recycling or the use of environmentally friendly materials. [1] The wastes consist of various kinds of materials, such as nonbiodegradable and hazardous matters are creating difficulties to manage the problem.

The EU has taken significant steps towards waste management and supporting policies aimed at reducing the impacts of waste on the environment and health and improving the resource efficiency of Europe. The objective is to turn Europe into a recycling society, avoid waste and, wherever possible, use inevitable waste as a resource. The goal is to achieve much higher recycling levels and minimize extraction of additional natural resources. Proper waste management is a key element in ensuring resource efficiency and European economies' sustainable growth.To achieve an overall benefit, biodegradable materials must offer advantages for waste management systems. [2] This paper examines the possible effects of biodegradable materials through landfill, incineration, recycling, reuse and composting, with specific reference to use, and waste management. It gives an overview of the critical issues of the life cycle that inform determinations on the benefits such materials have in relation to conventional counterparts.

2. Biodegradable Materials

Biodegradable waste contains various types of organic matter which can be broken down into carbon dioxide, water, methane or simple organic molecules by microorganisms via composting, aerobic and anaerobic digestion or other processes.

Biodegradable matters can be obtained from municipal solid waste, food and paper waste, and biodegradable plastics. Furthermore, human waste, manure, sewage, sewage sludge and slaughterhouse waste is considered biodegradable.

2.1 Use of Biodegradable Materials

Due to the increase of population and waste products, waste management is necessary to be able to use the biodegradable matters. There are several ways have been found to increase the use of biodegradable materials in recent years.

2.1.1 Biodegradable food packaging

Food packaging is becoming a significant issue for food protection, quality, and environmental effects as well as food itself. Since the most of traditional food packaging contains non-renewable resources and causes environmental pollution, biodegradable packaging might be a developing alternative. Some of these packaging alternatives are not only biodegradable but also edible and by the changing consumer demands, they are district options with such materials for food industry.

Scientists have been maintaining the researches about the potential of biodegradable films for packaging. [3]

Biodegradable packaging is created to eliminate the use of the polyethylene film utilized for various purposes. Such materials have preferable properties over conventional non-degradable plastics. They are impervious to humidity and physical changes for a time of half a month or more. This permits more prominent adaptability manuring process. They don't contain polyethylene, don't leave remnant after composting and are produced using sustainable biomaterials (polyester inferred from corn dextrose). A relative research about penetrability of the biodegradable film for oxygen and carbon dioxide demonstrated that films with low penetrability adversely influenced the nature of the organic product. Be that as it may, when the porousness of the biodegradable movies is into line with the breath of the natural product, the avoidance of defilement by microorganisms accomplished a beneficial outcome on the strength and quality.[4]

Table 2.1: Properties of Biodegradable, Paper and PE Bags [31]

Properties	Biodegradable Bag	Paper Bag	PE Bag
Biodegradable	+	+	-
Compostable	+	+	-
Resistant to tearing	+	-	+
Waterproof	+	-	+
Fat resistant	+	-	+
Can be welded	+	-	+
Can be printed	+	+	+
High resistance to melting	+		+

As it is seen on the Table 2.1, biodegradable bags satisfy desired properties such as resistance as well as biodegradable and compostable which Polyethylene bags can not satisfy [4].

2.1.2 Biodegradable Electronics

Production and consumption of conventional non-biodegradable material in electronics cause the similar environmental problem. To avoid this problem eco-friendly materials have been taking place in electronic industry for a better adaption of materials to the environment. This industry is developing in area of health sector, technological equipment, and communication sensors. By the preferences of organic materials such as the mechanical strength with adaptability; nontoxicity and the property of not causing inflammation; and the capacity to act as ionic and electronic conductors, they are used in biological systems. Studies on biodegradable materials for biodegradable electronics, are consist of material's breakdown chemistry and figuration, production process, appliance assembling. Combination with degradable inorganic dielectrics, metals, and polymers facilitate biodegradable electronics with advanced processing feature. Various biodegradable appliances are utilized with the inclusion of thermal treatment, pressure sensor, radio frequency electronics, batteries, organic photovoltaics. [5]

Organic materials are highly adequate to create technology that is functional, sustainable and biodegradable. Studies in the field of the bio-integration of electronics is developing quickly thanks to what organic materials offer. The thought of biodegradability and maintainability of organic electronic is in its earliest stages today. As seen in Fig. 2.1 ongoing showings of organic electronic dependent on biomaterials have demonstrated that green hardware have capacity and, ideally, are ready to have a constructive outcome in the future. [6]

Fig. 2.1: Biodegradable semiconductor developed by Stanford engineers shown on a human hair. [32]

2.1.3 Drug Delivery

In drug delivery, artificial polymers called dendrimers are used in biomedical owing to its distinctive features. However, they have negative effects on living beings caused by their nonbiodegradability feature. Dendrimers cause aggregation of synthetic polymers in cells and toxic effect in conclusion.

Using biodegradable drug carriers has various advantages such as to expand the solvency of hydrophobic medications and shield them from debasement and undesired collaborations with natural condition; the likelihood to delay dissemination time of medications by avoiding filtration and evacuation by the kidneys since nanoparticles bigger than 5 nm surpasses the renal limit and are less inclined to be separated by kidneys; the opportunity to inactively focus to tumor tissues by means of upgraded porousness and maintenance impact; the possibility to convey distinctive medications through physical exemplification and substance conjugation in the meantime, accomplishing synergetic treatment and in addition tunable and enhanced pharmacodynamics; the likelihood to adjust the dendrimer surface with utilitarian particles to bless them explicit properties, for example, imaging, outperforming natural hindrances, focusing to explicit tissues or cells, etc.; the capacity to accomplish controlled medication conveyance by tuning dendrimer/tranquilize associations or by creating boosts responsive medication bearers; the ability to corrupt to little sections under physiological conditions and be removed from body; and to decrease symptoms to ordinary tissues and organs, and to assuage the patients' agony. [7].

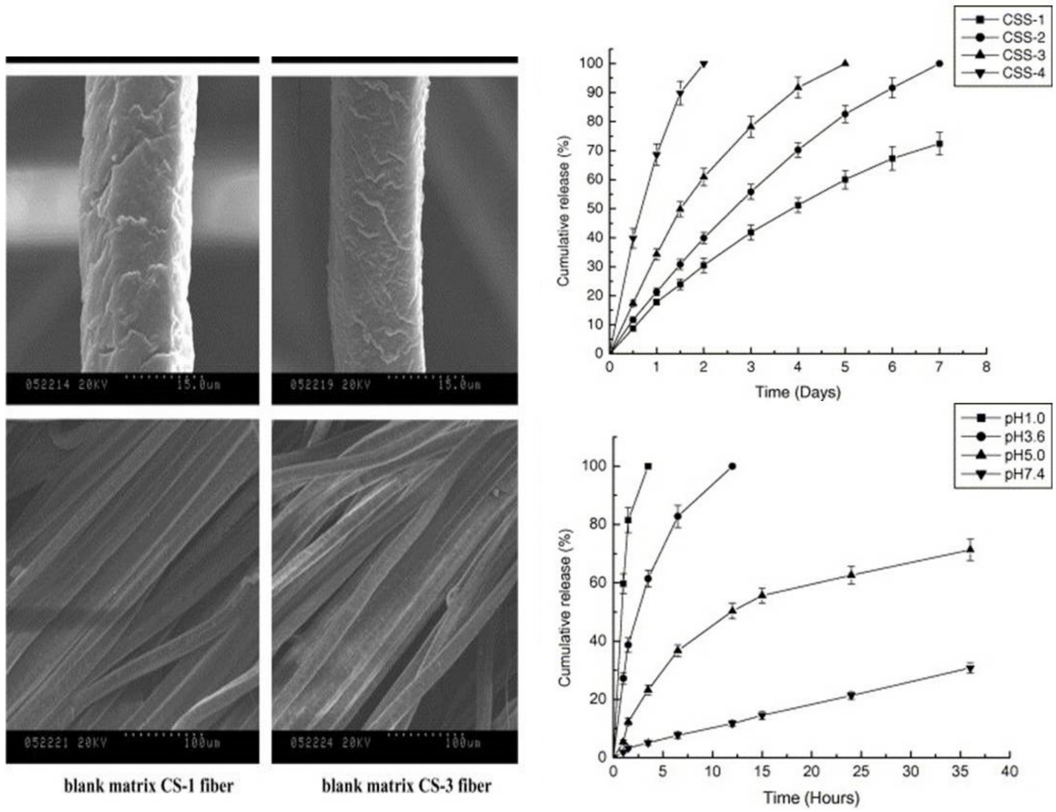

Fig. 2.2: Biodegradable and biocompatible Chitosan Fibers for drug delivery [7]

The fibers in Fig. 2.2 show the release of drug to wound for a faster healing.

2.1.4 Biodegradable Stents

Endovascular stents are the most imperative implantation appliances in cardiovascular intercession, and their viability decides the accomplishment of cardiovascular sickness treatment. Therefore, to eliminate negative reactions of lasting metallic stents, another age of endovascular stents called "biodegradable stents" is presently being created and considered as the most encouraging applicant. Biodegradable stents investigate over recent two decades has been predominantly centered around biodegradable polymeric, press, magnesium-and zinc-based stent materials.

The widespread metal type of stents may cause health complications after improvement of the human body. Operating with biodegradable stents which is consist of biodegradable polymeric materials is considered to assisting the vessel wall for several months. Then, the vessel wall will be remedied, while the implanted biodegradable stents will degrade without any harmful object being left. [8]

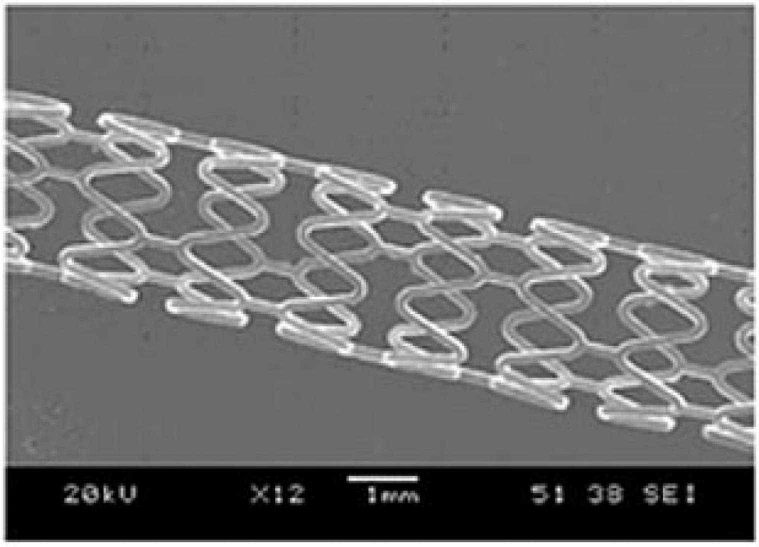

Fig. 2.3: Biodegradable magnesium alloy stents for the treatment of hardening arteries. [8]

In Fig. 2.3 there is the biodegradable stent which is put to prevent artery walls thicken which causes heart disease.

2.1.5 Biofuels

Biofuels are inflammable fuels produced from biomass. They have types as solid, liquid and biogas or syngas.

One of the major types is ethanol which is nontoxic and biodegradable and produced from biomass such as grain and crops. Producing and consuming ethanol results in emanations of carbon dioxide (CO_2), an ozone harming substance. On the other hand, ethanol is viewed as climatic carbon-neutral claiming corn and sugarcane, the two noteworthy feedstocks for fuel ethanol generation, ingest CO_2 as they develop and may counterbalance the CO_2 delivered when ethanol is made and consumed. Some ethanol makers consume coal and flammable gas for warmth sources in the maturation procedure to make fuel ethanol, while some consume corn stocks or sugar stick stocks.

The impact that expanded ethanol utilize has on net CO_2 discharges relies upon how ethanol is made and regardless of whether roundabout effects ashore utilize are incorporated into the computations. Developing plants for fuel is a questionable subject since a few people trust the land, manures, and vitality used to develop biofuel yields ought to be utilized to develop nourishment edits. [10]

Second major type of biofuel is biodiesel which is made from animal fat and vegetable oil. Using renewable biodiesel for vehicles in place of nonrenewable fuel diesel provides to reduce greenhouse gas emission. Biodiesel fuel has concoction attributes like oil-based diesel, so it may be utilized as an immediate substitute for diesel fuel. Biodiesel fuel can likewise be mixed with oil diesel in any rate without reducing the vehicle efficiency.

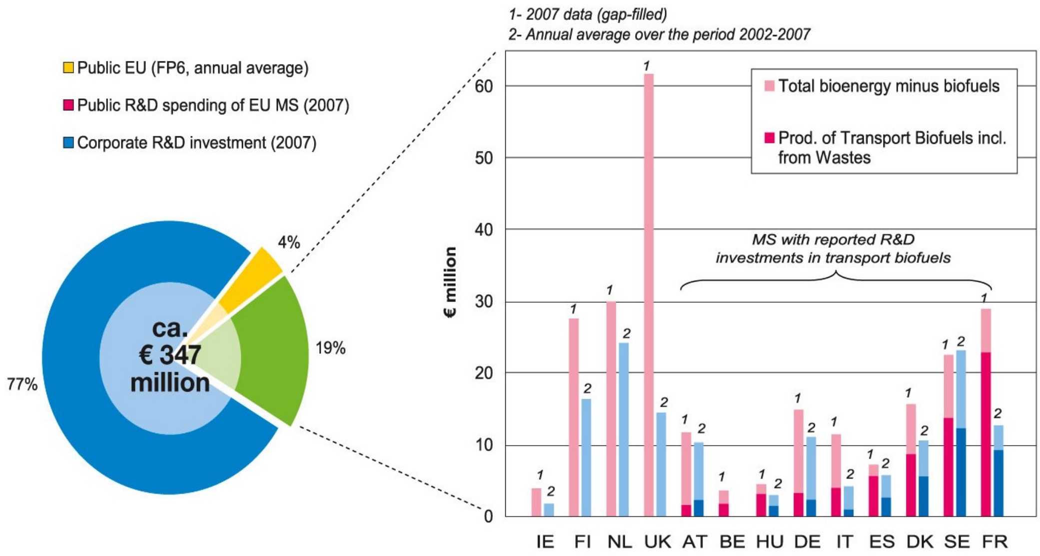

Fig. 2.4: R&D investment in transport biofuels [11]

Fig. 2.4 shows the investment in industrial and public transport. British and Finnish companies do not give a clear interest to R&D for biodiesel even though French, Swedish and such companies give high funds to investments.

2.2 Types of Biodegradable Materials

Biodegradable waste contains various types of organic matter which can be broken down into carbon dioxide, water, methane or simple organic molecules by microorganisms via composting, aerobic and anaerobic digestion or other processes.

Biodegradable matters can be obtained from various sources on earth.

2.2.1 Biodegradable Municipal Solid Waste

Municipal waste is produced by households and workplaces. The created municipal waste quantity is the gathered waste and disposed waste by the competent applying the waste management rules. MSW contains mostly the biological material such as food waste from the kitchen, paper component and partly textile waste. [12]

2.2.2 Wood and wood shell from forests

Wood is a renewable and sustainable energy source and has advantages over other energy sources. CO_2 emission and heavy metal content are less than fossil fuels. Using wood as fuel has combustion, gasification, cogeneration, and cofiring methods.

2.2.3 Agricultural waste

The definition of agricultural waste of United Nations is the waste produced from agricultural process. It contains wastes from farmstead, poultry houses and slaughterhouses; harvest waste; manure; pesticides inside water, air or soils; and salt and silt from fields. [13] Agricultural waste is a great potential of waste that is used to supply increasing energy demand.

2.2.4 Nutrition industry waste such as production residues

Waste of the nutrition production contains various kinds of food processing residues, such as rice bran, bean curd residue, and other ingredients' residues, all of which are counted as industrial waste.

2.2.5 Sludge from biological treatment of wastewater

By processing the wastewater from organic impurities or a mix of industry and municipality having solvent of wastewater sources, sludge is obtained in sludge treatment plant to reuse in agricultural land, landfilling or incineration.

All the wastes that mentioned above are degradable either in the presence of oxygen-aerobic- or without oxygen-anaerobic- which have various speed depends on the environmental and material conditions.

To reduce the ecological effect and asset utilize, organic waste treatment and elective answers for sewage treatment are regularly upheld. These options incorporate expanded rural utilization of waste residuals. To dissect whether such proposed frameworks demonstrate upgrades for the earth and its supportability, frameworks investigation is a valuable strategy. The progressions in natural effect and asset utilize isn't just a consequence of changes in waste treatment strategies, yet in addition generally an aftereffect of changes in encompassing frameworks (vitality and horticulture) caused by changes in waste administration rehearses. [14]

2.3 Treatment of Biodegradable Waste

There are various types of treatment processes for biodegradable wastes. The most preferred ones are mentioned below.

2.3.1 Landfill

Landfill is disposing the wastes in a landfill area which is isolated from the surrounding environment to prevent the contamination of the water and air. The earlier practices of landfill are not considered healthy and safe due to the dangerous gas and liquid leakage as well as the large area used for this technic. By the European Policies of waste management, the undesirable effects must be avoided as much as possible with the requisition of Directive 1999/31/EC. The directive includes the categorization of wastes, treatment before landfilling, prevention against contamination, process rules for operations etc..[15]

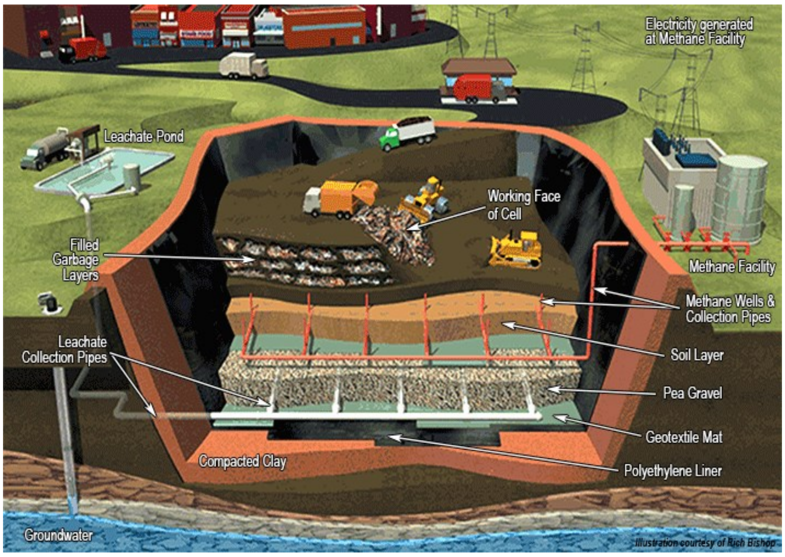

Fig. 2.5: The Complete landfill cell [34]

The Fig. 2.5 is a modern and complex type of landfill example such as North Wake County Landfill 2,500 tons trash inside the cell. The landfill consist of cells trash will be disposal. By the developed structure of the system it will prevent the contamination of air and groundwater. [16]

2.3.2 Incineration and Thermal Treatment

Incineration is the combustion process of raw or remaining wastes with the help of oxygen which releases heat, carbon dioxide, water and some residual carbon at the end of reaction. This technology is more preferred due to the various energy content of wastes. The calorific values of wastes changes from about 1.8 to 4 GJ/ton for food waste to about 35 GJ/ton for some plastics. [17]

The European Waste Incineration Directive 2000/76/EC has the purpose of reducing the undesirable effects of incineration and co-incineration of waste to the environment and human health by the technical and operational rules and limits. Thermal treatment of waste is a significant method of waste management to reuse of materials and obtain energy. This technology includes pyrolysis and gasification of wastes which are based on treating the biodegradable materials and plastics. Therefore, it is necessary to eliminate nonflammable materials and recyclables and excess moisture and shredding reduce the size. [18]

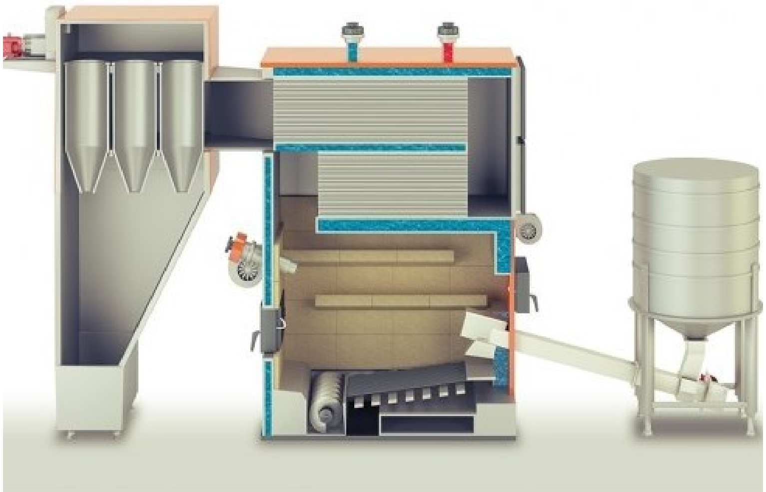

Fig. 2.6: Thermal treatment plant for MSW [19]

Fig. 2.6 shows the thermal treatment plant which has the gasification and pyrolysis processes to the municipal solid waste.

2.3.3 Waste Water Treatment

The technology depends on the size of the territory and on the required output quality of the treated wastewater. The first part of the wastewater treatment plant is coarse pre-treatment which removes coarse impurities from the water inflow. Then, mechanical treatment separates fine pollutants which did not dissolve in the wastewater. Biological treatment removes the dissolved organic pollution by biological processes in the activation tank and separates sludge from the treated wastewater in a settling tank. [40]

Before the wastewater is discharged, it is necessary to reduce nitrogen concentration. Biological processes are used to remove phosphorus during the treatment. In big wastewater treatment plants, chemical precipitation of phosphorus is used.

Fig. 2.7: Wastewater treatment plants [40]

The wastewater treatment plants as in Fig. 2.7 include gas handling and sludge treatment systems. For each wastewater treatment plant, the Water Authority issues the permit to discharge wastewater. The permit defines outflow limits and sampling frequency for the wastewater treatment plant. [40]

3. European Legislation of Waste Management and Comparison with Legislation in Turkey

The EU is the pioneer about biodegradable waste management. Each year 120 to 140 million tons of bio-product are delivered in the EU. This relates to around 300 kg of bio-product delivered per EU native every year. Biowastes can be utilized to acquire biodegradable wastes through treating the soil, anaerobic processing or another preparing innovation; or even to get biofuels such as biogas or bioethanol. Although the creation of biowastes can be altogether different and variable and the assurance of generation elements can be confounded, these products could be incorporated into the model as another sort of waste independently. If the essential information is accessible, squanders of this type are considered with the blend of the remaining squander after the division of plastics, glasses, paper, and metal. [20]

Due to the increase of population and waste products, waste management is necessary to be able to reuse the biodegradable matters. There is a waste hierarchy as prevention, reuse, recycling, energy recovery and disposal. There are criteria for all these steps of hierarchy to apply to wastes. The European Union defines regulations for all member states should apply waste management programs in their country. These regulations need to incorporate an advanced examination of every single waste stream, existing frameworks for gathering, recuperation and disposal. 42% of municipal waste is landfilled, 38 % is recovered and 20 % is incinerated in Europe. Fig. 3.1 is showing the management of municipal waste of European member states.

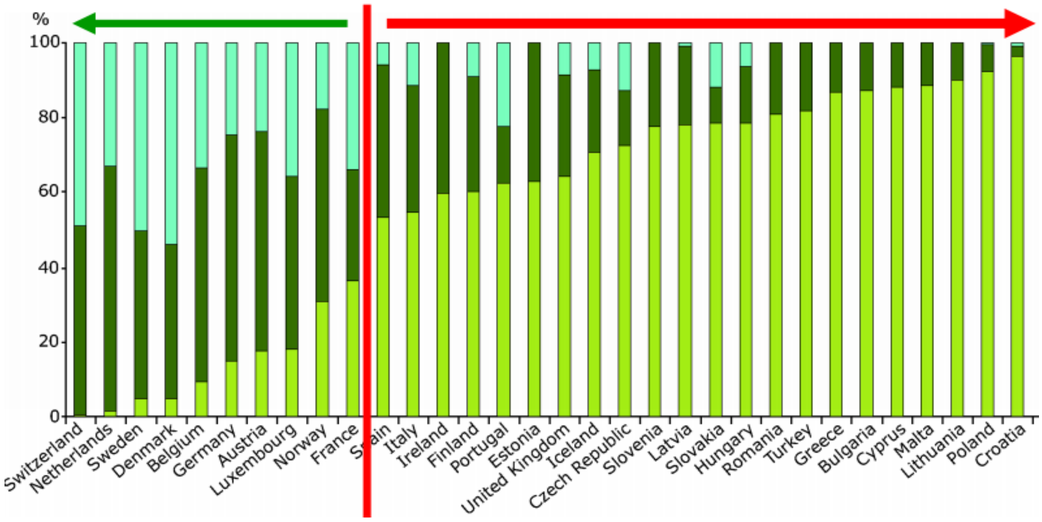

Fig. 3.1: Recycling, incineration and landfilling of municipal solid waste in Europe [21]

3.1 Waste Management in Turkey

As a developing country, Turkey has an increasing population and a production of waste day by day. Since being the official candidate of European Union, Turkey has started to search for more efficient waste management solutions. According to the EU regulations, a combined method for waste management which includes avoiding and/or reducing to produce waste, recycling, and applying treatment is essential. This method has been applied in European countries for decades. In Turkey, the Environmental Laws are regulating the waste management process. The disposal methods which are the most regarded parts of waste management process in Turkey contains landfill, incineration only for medical wastes, sterilization, composting and disposal methods. [22]

Today the Ministry of Environment and Forestry is the policy maker and the director for waste management which shares the mission with different authorities. TURKSTAT data for the year 2004 claimed that, the gathered solid waste 34 million tons annually and quantity of solid waste per capita is 1.34 kg on average per day. [23]

The basic problems about waste management in Turkey are disregarded recycling and sanitary disposal and improper landfill operations. Furthermore, there are financial problems and deficiency of facility and educated personnel. To achieve a better management plan, Ministry of Environment and Forestry determined the geographical regions for waste management.

In Marmara region, the population and industrial activity cause a great amount of waste production. Istanbul, Bursa, and Kocaeli cities in this region store 90 % of their total waste in sanitary landfills.

In Aegean region, especially in the most developed city Izmir, increasing population and industrial activities can be seen. Despite the quantity of wastes, there is not enough landfill and disposal methods in use. As an alternative landfilling area, the city of Denizli has the purpose to have developed facilities for Aegean region.

In Central Anatolia region which has the capital of Turkey, Ankara, the generation of solid waste is more than 0.90 kg per day and person and the disposal method is landfilling.

The Mediterranean region has the waste production from 0.90 to 1.00 kg per person and per day. Landfill areas are mostly located in the central cities such as Adana.

The Black Sea region has the waste production around 0.94 per person and per day in the biggest cities such as Samsun. The sanitary landfill plants are mainly located in Samsun and Trabzon. There is a waste management project in the Black Sea region with the aim of landfilling, treatment and sterilization methods. [24]

The East and South East Anatolia regions have the biggest amount of waste in their cities which has the biggest population. The sanitary landfill areas have been increased since 2007 until today.

The well-known plants for hazardous waste treatment in Turkey are IZAYDAS and PETKIM.

3.2 Waste Management in Czech Republic

Waste management is a continuously developing sector in Czech Republic since the acceptance of first Waste Act in 1991. More advanced and also currently used act in 2001 which has additional regulations in years, includes reducing waste, defining the order of waste handling and environmental protection. The fundamental topic in waste management is to define the waste hierarchy which includes:

- Waste prevention,
- Preparation of waste for re-use,
- Recycling of waste

- Recovery,
- The disposal of waste.

Czech Republic has been and will be pursuing the Waste Management Plan between 2015 and 2024. The authorities about the waste management are Ministry of the Environment, Czech Environmental Inspectorate, Municipalities and other state units.In case of municipal waste management, Fig. 3.2 indicates the waste management methods in Czech Republic between 2009-2012.

Fig. 3.2: Production of municipal waste in the Czech Republic in the period 2009 - 2012 [35]

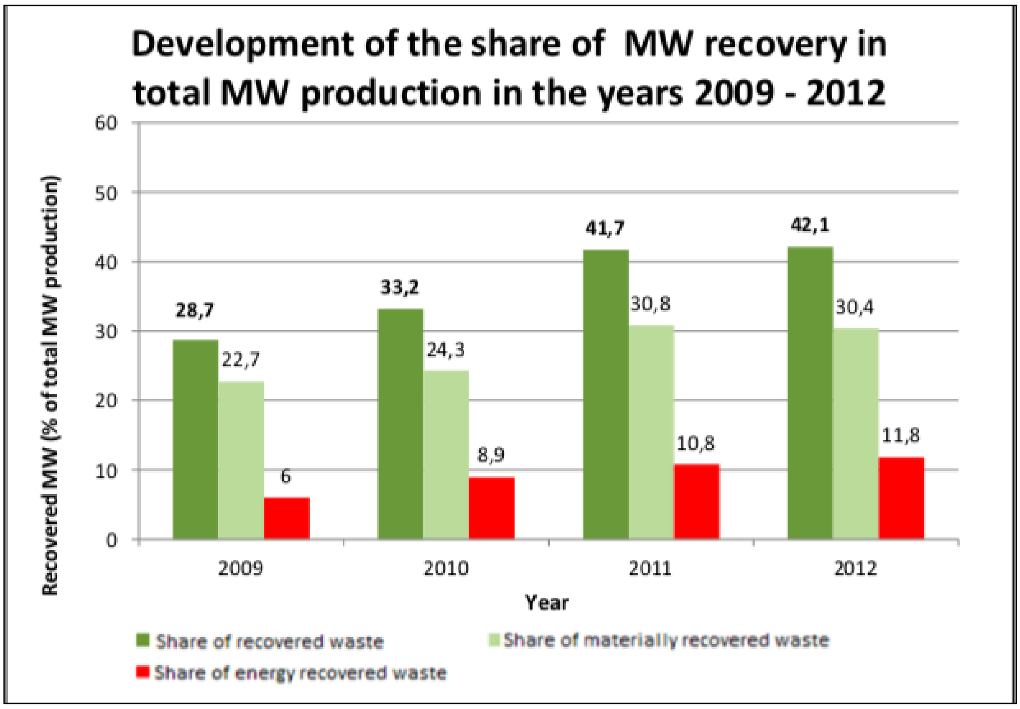

Fig 3.3: Recovery of municipal waste in the Czech Republic in the years 2009-2012 [35]

As in Fig. 3.3, between 2009 and 2012, recovered waste material quantity is increased and landfilling is decreased to reduce the waste production and provide the environmental protection by the regulations of EU.

In recovery of waste, there is not enough improvements in the past few years. In 2012, the landscaping method seems the most extensive method with recycling and improvement of materials.

The tendency of waste management in the Czech Republic follows the waste management hierarchy by a majority, nonetheless in the area of municipal waste management the implementations is not being obtained in the long term. [25]

3.2.1 Waste Treatment Capacities in Czech Republic

Landfills

- Inert Waste: 31,
- Hazardaus Waste/Combined: 26,
- Non-Hazardaus Waste: 148.

Incineration

- Municipal Waste: 3,

- Hazardaus Waste: 28.

Co-incineration

- Cement Kilns: 5.

Energy recoery of municipal waste

- SAKO Brno: 240,000 tons/year,
- ZEVO Praha Malešice : 310,000 tons/year,
- TERMIZO Liberec : 96,000 tons/year.

Facilities mainly for bio-waste/biomass

- Composting plants: 239,
- Comunity composting: 52,
- Biogas powerplant stations: 326,
- Biogas Waste Stations: 10. [26]

According to Waste Framework Directive 2008/98/EC, in the waste hierarchy, the most desired solution is waste prevention; the last desired is the disposal of waste. Day by day, EU countries are trying to decrease the lanfilling. In Czech Republic the number of landfilling area is decreasing while the number of recovery facilities is increasing.

The recovered waste in total waste production increased throughout the period 2009-2012. In 2012, the recovery of total waste production compared to 2009 increased, material recovery of the total waste production has increased compared to 2009. Energy recovery from waste in the total production of waste is low throughout the period, at around 3 %.The share of waste disposed of in landfills in the total waste production decreased from 2009 to 2012 about 2 percentage points.[35]

4. Experiments

Increasing calorific value of biodegradable material by drying has four different methods. The first one is solar drying method which has advantages as better quality of product, preventing fuel dependence, and reducing environmental impact. Main disadvantages of this method are requirement of adequate solar radiation and need for time to dry. For the method of biodrying the main advantage is waste mass reduction, reduction of CH_4, CO_2, SO_2, NO_x emission and dust emission from waste lanndfills. The main disadvantages is the process is highly complex, and requires the optimization of parameters. Third drying method is biostabilization which is useful for reducing the environmental pollutions but it need more time than biodrying method.

The final method is thermal drying which includes oven drying method has large number of samples and high accuracy. However it has high risk of error when using manuel data entry and decomposition chance of material.

4.1 Methods of Increase Calorific Value of Biodegradable Materials

Calorific value is quantity of energy generated by the complete combustion of a material or fuel which has units of energy per amount of material, kJ/kg. High calorific value is obtained by a bomb calorimeter contains the latent heat of water vapour formed by the combustion of the hydrogen. The low calorific value is acquired from subtracting this latent heat. The measurement of high calorific value is complex operation that requires set-up, measurement and calculation work. In lack of these measurements there are proximate and ultimate analyses, which may be done out easily and cheaply by using advanced laboratory equipments. [27]

There are several methods to increase calorific value mostly based on drying methods. Drying is is the most crucial biomass preparation therapy. Unprocessed biomass is wet with high water content with 30 - 60 %, so drying is necessary to reduce moisture with 10 - 15 % and enhance energy use properties as in Fig. 4.1.

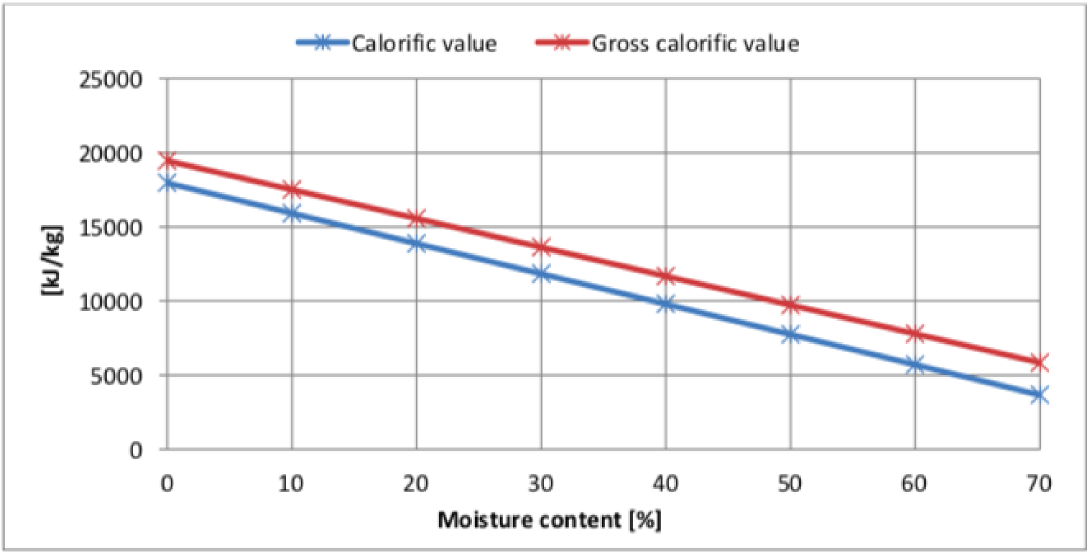

Fig. 4.1: Moisture Dependence of Calorific Value [36]

In Fig. 4.1, wood chips are used as fuel with 19769 kJ/kg gross calorific value. It is seen that calorific values have inverse ratio with moisture content of material and it is decrasing with the increasing moisture content. [36]

Biomass dryers can be classified according to drying principles as direct, indirect, radiant and combined. Indirect dryers use heat transfer through direct contact on a heated surface between materials. A heated surface separates the drying medium and the dried material. The primary heat source is overheated steam. Heat resistance is low and moisture is vaporized in drying medium. It is possible to reuse the waste heat and flue gases. Direct dryers use as a drying medium hot air or hot flue gases. In the drying space, heat and mass transfer occurs.

4.1.1 Solar Drying Method

In solar drying the heat is obtained by the sun radiation and it is an environmental friendly drying method. Solar dryer is designed for drying agricultural products by removing the moisture.

Direct Solar Drying

In direct solar drying in Fig. 4.2, moisture is removed from top when air enters into chamber from below and exits from top. With the sunlight on glass surface, light is absorbed, reflected back from the glass, and transmitted. The absorption of light on surface increases temperature. The glass cover decreases direct convective losses to environment. The main disadvantage of direct solar drying is that the absorbed is not in control.

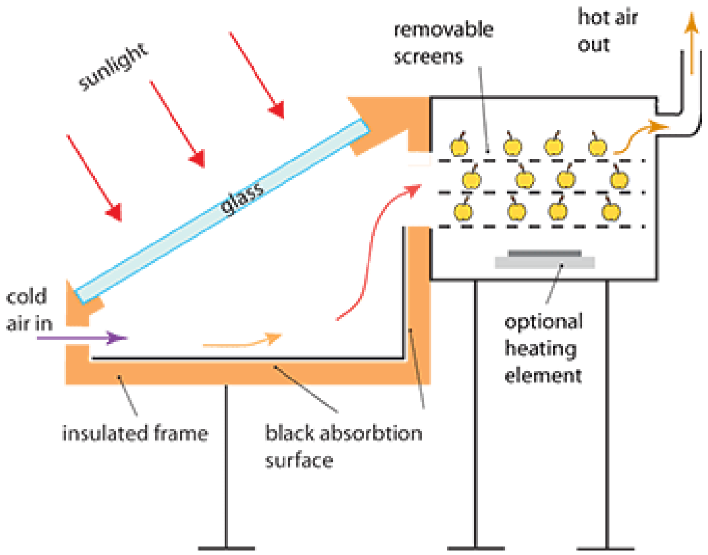

Fig. 4.2: Direct Solar Dryer [37]

Indirect Solar Drying

The indirect solar dryer as in Fig. 4.3 is consist of a solar collector which is producing electricity and a drying unit. The solar collector has an absorber obtained from a corrugated iron absorber coupling and a porous absorber made from an aluminum mesh. A portion of the solar radiation received on its collecting surface is converted into heat. Thus, through convective heat exchange, the air that crosses its porous absorber receives a portion of this energy. It is the new technique of product drying with higher efficiency than the direct type of solar drying. In this method the atmospheric air is heated in flat plate collector or concentrated type solar collector. The heating process is either passive or active. This hot air then flow in the cabin where products are stored. Therefore moisture from the product may lost by convection and diffusion. Drying rate is high as compared to the direct solar dryer. [28]

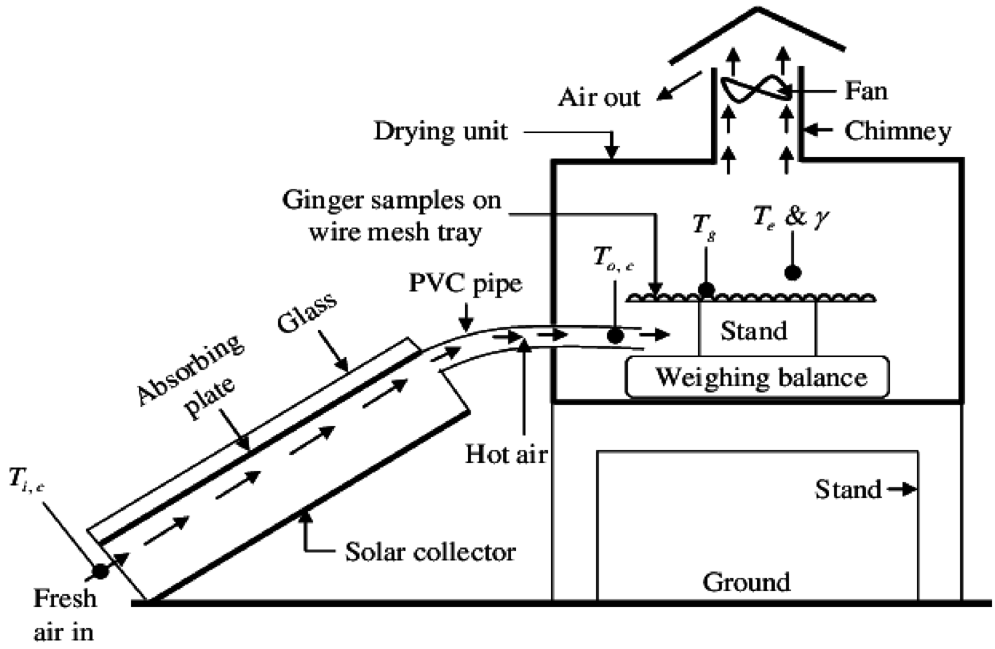

Fig. 4.3: Indirect Solar Drying [38]

4.1.2 Biodrying

Biodrying is a variation of aerobic decomposition, used among mechanical–biological treatment plants to dry and partly stabilise residual municipal waste. Biodrying plants will manufacture a top quality solid recovered fuel, high in biomass content. Here, method objectives, operational principles, reactor styles, parameters for method observation and management, and their result on biodried output quality are critically examined. among the biodrying reactors, waste is dried by air convection, the required heat provided by exothermal decomposition of the promptly complex waste fraction. Biodrying is distinct from composting in attempting to dry and preserve most of biomass content of the waste matrix, instead of totally stabilise it. business method cycles are completed among 7 – 15 days, with principally $H_2O(g)$ and carbonic acid gas loses. [29]

4.1.3 Biostabilization

Biostabilization involves the improved biological degradation of organic matter, which might scale back MSW weight and volume, and reduce the environmental pollutions, like leachate and landfill gas. The microorganism metabolism of the biostabilization is analogous to it of biodrying. The fundamental variations concern the preparation of materials to be processed, management criteria, method period, emission factors and energy balance. Time needed for an efficient biostabilization method is way longer than that of biodrying . Through innovative technologies for waste treatment, bio-stabilized materials will be used for agricultural functions and kept safely in an exceedingly landfill whereas bio-dried materials can be used as an energy supply like fuel. [30]

4.1.4 Thermal Drying

The dewatering choice is known as thermal drying once an external auxiliary energy supply permits the heating of the waste. Throughout thermal drying, a major quantity of thermal energy has to be moved to the moist solids to vaporize the water and to heat the solids and residual water. Thermal drying technology is predicated on removal of water from dewatered solids that accomplishes each volume and weight reduction. The additional advantage of thermal drying is that it usually leads to a product with vital nutrient worth. Typically, dewatered solids are delivered to a thermal drying system, wherever most of the water is removed via evaporation leading to a product containing approximately ninetieth solids. within the thermal drying system, the temperature of the wet solids mass is raised in order that the water is driven off as a vapor. By removing most of the water from the solids, thermal drying ends up in a big reduction in each volume and mass

Significant thermal energy should be transferred to the solids to extend temperature within the drying method. This energy are often provided by combustion of a spread of fuels (natural gas, autoclave gas, fuel, wood, etc.), by a utilize of waste heat, or by conversion of power into thermal energy.

4.2 Selected Fuels

Municipal solid waste is generally categorized into ecological wastes, paper, food and kitchen waste; recyclable resources and inert wastes. In the developing countries production of waste has been increasing how increasing of population and economic growth. One of the main problems is municipal solid waste as biodegradable waste such as food, kitchen waste, recyclable resources and inert wastes. these waste produce methane if we do landfilling and it has to be controlled more than 30 years this area after the closing. In lack of effective systems or waste management program it can be dangerous for the human and enviroment.

For the individual experiments, kitchen waste as orange and banana peel, apple and some leaf of vegetables are used as biodegradable material as their properties referred in Table 4.1 and 4.2. It is full of nutrients and organic materials, easy to access and economical for drying process.

Table 4.1: The properties of the examined waste samples for individual experiments

	Number of samples	**Amont of each sample** [g]	**Composition ratio (food waste and green leafs)** [%]	**Moisture Content** [%]	**Calorific Value** [MJ/kg]
Quantity Before Drying	9	300	80;20	80 ± 4	4 ± 1
Quantity After Drying	9	46	80;20	20 ± 4	12 ± 1

Table 4.2: Composition and properties of the selected waste materials [41, 42]

Type of Waste	**Density** [kg/m^3]	**Moisture** [%]	**Inert Residue** [%]	**Calorific Value** [MJ/kg]	**C** [%]	**H_2** [%]	**O_2** [%]	**N_2** [%]	**S** [%]
Food wastes	120-480	50-80	2.00-8.00	3.49-6.98	48.00	6.40	37.60	2.60	0.40
Garden Trimmings	60-225	30-80	2.00-6.00	2.33-18.61	47.80	6.00	38.00	3.40	0.30
MSW	87-348	15-40	NA	9.30-15.12	NA	NA	NA	NA	NA

MSW: Municipal Solid Waste, NA: Non-accessible

4.3 Selected Solutions

Solar drying is one of the oldest and basic form of drying methods used by humankind. This method is still used for drying of the agricultural products. However, drying process in open air may cause impurity of the products. Furthermore to increase the drying rate and make the process efficient indirect solar dryers can be a proper solution.

Second method is oven drying which is rely on natural convection. By this method, various samples can be used at the same time. Additionally, high volumes of material to dry is possible for drying ovens.

4.3.1 Solar Drying

The experiment is done VSB-TUO in Ostrava in September

Fig.4.4: Indirect Solar Drying System

1. Solar air collector Duo - completely ready to use
   - Collector + 2 integrated fans
   - Separate PV module with holder
2. Mini-dryer
   - Dryer with integrated fan
   - Digital sensors
   - Shelf space - stainless steel
   - Pipe connection
   - Dryer - Protective cover

As shown in Fig. 4.4 the device consists of air collector connected in parallel, a drying chamber and two fans. An apparent benefit of this design is that the temperature of the drying air from collectors is more stable as a result of the use of PV powered fans. The drying chamber, positioned below the collectors. The structure allows sunlight to directly irradiate materials to be dried and makes loading or unloading greengages more convenient. With the help of PV powered fans, the hot air from collectors flows to the bottom of the drying chamber through three connecting ducts, and inside each of them, an adjustable vent is installed. The mesh trays of materials to be dried are made of perforated stainless steel panels, and are fixed inside the chamber.

4.3.1.1 Design of Solar Drying Unit

Solar energy is one of the various kinds of energy source which may be used directly or indirectly to heat drying air through a solar collector. To minimize the drying time of products and energy use there have been significant researches. These studies contain energy and exergy drying process analysis to provide optimization for the system. In this work, an indirect discontinuous operating type of dryer is used without extra energy. It is composed of a solar collector, an air heater and a drying box as in Fig. 4.5.

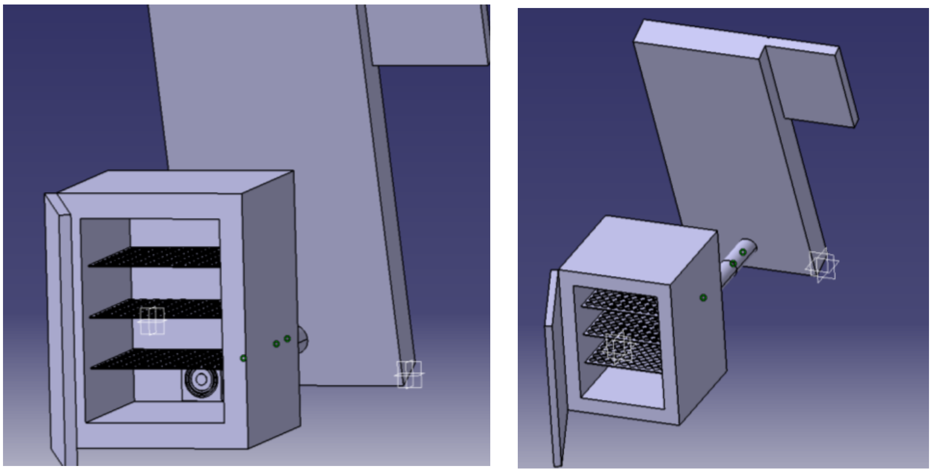

Fig. 4.5: Design of Indirect Solar Drying System and Sensor Distribution with numbers

4.3.1.2 Solar Drying Experiment

In the experiment process of a solar dryer, the physical and thermal properties of the product; moisture diffusion, heat and mass transfer, specific energy consumption, activation energy, their dependence on the input air velocity and temperature have to be taken into account. The efficiency of a solar dryer depends on the ambient air temperature, air flow speed, relative humidity, quantity, thickness and moisture content of the product to be dried and the intensity of the incident solar radiation.

Design parameters of the solar dryer :

1. The collector tilt γ for maximum incident solar radiation is usually taken as the latitude of the location, and is given by:

$$\gamma = 10^{o} + \text{lat}\varphi \qquad [^{O}] \qquad (1)$$

where latϕ is the latitude of the site location.

2. The ratio of length to width of the air heater was taken as 1.5 and the length of the drying chamber L therefore is given by:

$$L_s = \frac{A_{dc}}{w} \qquad [\text{kJ/ K}] \qquad (2)$$

where A_{dc} and w are the area and width of the collector, respectively.

3. The aggregate thin drying layer thickness $h_L \leq 200$mm was used.

4. The quantity of moisture to be removed m_w was obtained according to the relation:

$$m_w = w_w \frac{m_i - m_f}{1 - m_f} \qquad [\text{kg}] \qquad (3)$$

Where, m_i initial moisture content, m_f is final moisture content, w_w is initial product mass.

5. The total volume of air needed to remove the moisture was obtained using the relation:

$$V_A = \frac{m_w L_t R_a T_a}{C_{pa} P_a (T_o - T_f)} \qquad [\text{m}^3] \qquad (4)$$

Where, R_a is specific gas constant, P_a the partial pressure of dry air in the atmosphere, c_p the specific heat capacity of air at constant pressure, T_f the temperature of air leaving the drying chamber, T_a the ambient temperature, L_t the latent heat of vaporization of water.

6. The volume air flow rate was then obtained from the relation:

$$\dot{v} = \frac{V_A}{t} \qquad [\text{m}^3/\text{s}] \qquad (5)$$

Where, t is total time needed to dry a given sample of the product.

7. Thermal efficiency of the solar collectors was obtained according to the equation:

$$\eta_c = \frac{mC(T_o - T_i)}{A_c I} \times 100 \qquad [\%] \qquad (6)$$

Where, m is air mass flow rate, c specific heat capacity of air, T_i collector inlet air temperature, T_o outlet air temperature, $I_{incident}$ solar radiation and A_c the collector area. A plot was then made of the thermal efficiency of collector against time.
8. The system drying efficiency for the solar dryer was calculated according to the equation:

$$\eta_p = \frac{m_w L_t}{IA_c + P_f} \quad [\%] \qquad (7)$$

m_w is weight of water evaporated from the product, L_t is the latent heat of vaporization of water , P power used to drive the fan.

Table 4.3: Parameters of Indirect Solar Dryer System

Quantity	Description	Values	Unit
w_w	Mass of product to be dried	2,7	kg
m_i	Initial moisture content of product	79,83	%
m_f	Final moisture content of product	19	%
t	Total time of drying	7	h
m_w	Mass of water evaporated	2,28	kg
V_a	Volume of air needed to evaporate moisture	164,99	m^3
	Volume air flow rate	103	m^3 /s
n_c	Collector system efficiency	41	%
n_p	Drying efficiency	6,27	%
R_a	Specific gas constant	287,1	J/kgK
P_a	Partial pressure of air in atmosphere	101	kPa
C_{pa}	Specific heat capacity of air	1007	J/kgK
L_t	Latent heat of vaporization of water	2260	kJ/ K
T_f	Temperature of air inside drying box	332	K
T_o	Temperature of inlet of drying box	307	K
T_a	Ambient air temperature	284	K

Table 4.3 has the parameters of solar drying system which are the results of the calculation depends on experiment data and constants of air and water. The drying tests on food waste were conducted using the indirect forced convection solar dryer under full load conditions, during the dates 7th-21st of September 2018, between 7:00 and 14:00 h which is shown in Table 4.3 with other solar system parameters. The performance of the dryer was evaluated for drying of

300 g food waste with an initial moisture content of 79.83 % loaded in thin layers on each of the trays as in Fig. 4.7. Average outside temperature value at the period between the hours 7:00 a.m. and 2:00 p.m. was 11.2 °C. The average temperature of the drying air at the inlet of the drying chamber was 52 °C. During the experiments, maximum air temperature in the dryer chamber was 34 °C.

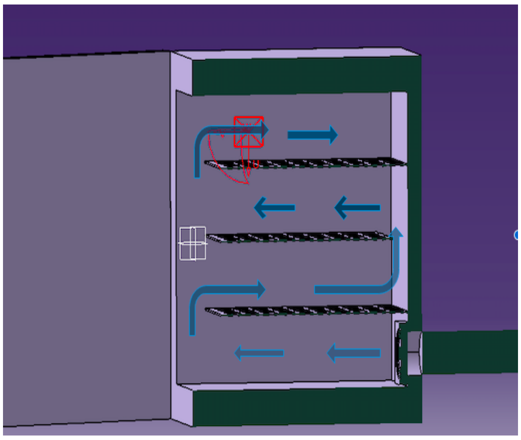

Fig. 4.6: Direction of the air flow in dryer box: The tray in the middle has a 5 cm distance to the wall while the other trays are attached.

There are the sensor numbers which were used to measure the temperature and relative humidity as shown in Fig. 4.7. The direction of the air flow is shown between three layers in Fig. 4.6. The layer in the middle has 5 cm gap was arrange to increase the chance of homogenous air distribution to dry the materials equally.

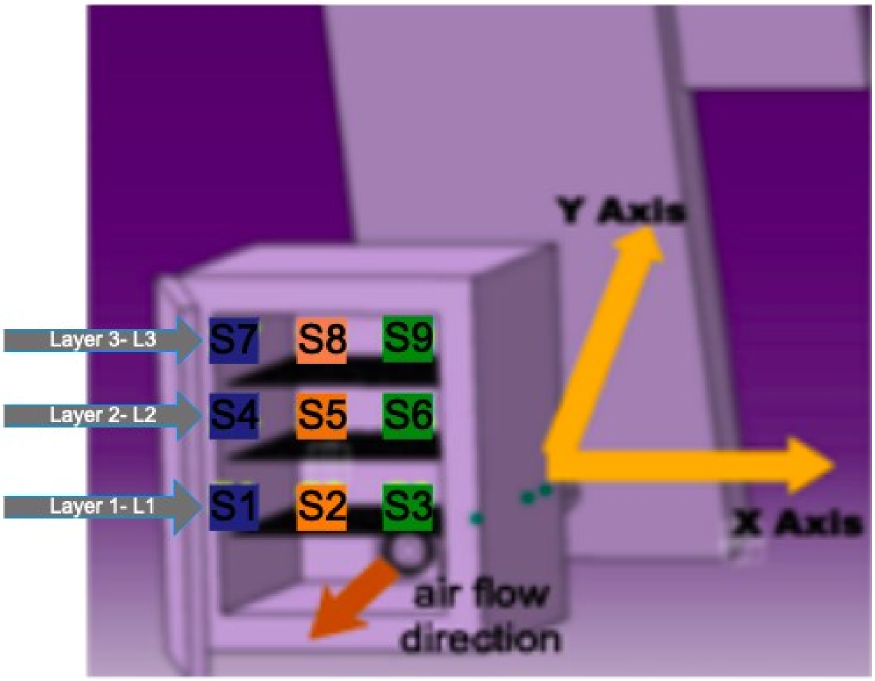

Fig. 4.7: Drying Box Front View of Distrubition of Temperature and Relative Humidity Sensors in X direction in the order of : 1st layer has S1,S2,S3 ; 2nd layer has S4,S5,S6; 3rd layer has S7,S8,S9.

4.3.1.3 Results, Solution and Discussion to the Solar Drying Systems

In Fig.4.8, the inlet and exhaust air and heat losses are shown. The heat loss calculation of this part of the system is done below.

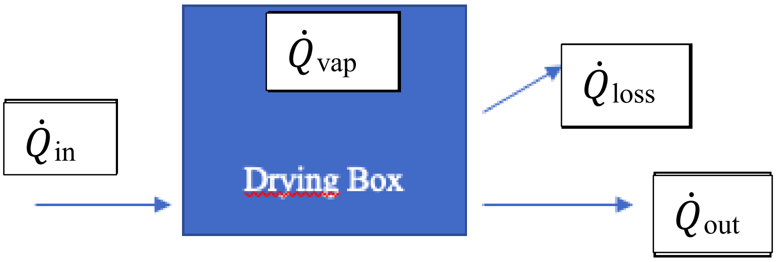

Fig. 4.8: Heat Loss of Drying Box

Calculating the heat inlet to drying box

$$\dot{Q}_{in} = \dot{Q}_{out} + \dot{Q}_{loss} + \dot{Q}_{vap} \qquad [KJ/h] \qquad (8)$$

$$\dot{Q}_{in} = c_p.\dot{V}.\rho.t = 44035{,}90 \text{ KJ/h}$$

- specific heat capacity of air c_p = 1,01 KJ/kg K

- volume airflow $\dot{V}$ = 103,00 m^3 /h

air density ρ = 1,21 kg /m^3 (calculated online according to Ostrava altitude, temperature and barometric pressure in September)

- air temperature at air inlet of drying box t= 332 K

Calculating the heat consumed to vaporized water

$\dot{Q}_{vap} = m.\ c_p.t + L_{heat}.m = 5{,}65$ KJ/h

- specific heat capacity of water c_p=1,00 KJ/kg K
- mass of water to vaporized m= 2,28 kg
- temperature inside drying box t= 307 K

Calculating the heat output of drying box

$\dot{V}_{final} = \dot{V} + \dot{V}_{vap}$

$\dot{Q}_{out}$= 29,360 KJ

- specific heat capacity of air c_p = 1,01 KJ/kg K
- air density ρ = 1,21 kg /m^3
- the air temperature at outlet of drying box

Calculating Heat Loss of Drying Box

- $Q_{loss} = Q_{in} - (Q_{out} + Q_{loss}) = 0{,}426$ [KJ/h]

Below, inside temperature-time relations are shown in Fig. 4.9, 4.10 and 4.11 and relative humidity-time relations are shown in Fig. 4.12, 4.13 and 4.14. It is shown that the the inside temperature starts to increase during experiment and has the maximum inside temperature for all layers after four hours. After this time the temperature decrases until the average 34 C^0 degree. Relative humidity which shows amount of moisture in the air compared to the amount the air can hold at that temperature has an inverse ratio with temperature. When we raise the temperature while keeping moisture content constant, the relative humidity decreases. The reason there are three different layers and nine sensors is to see the effect of humidity and temperature distribution based on locations of samples. The average humidity and temperature measured by different sensorsa are similiar and the differences can be neglected. To see the results and differences clearly, distances can be made wider between samples.

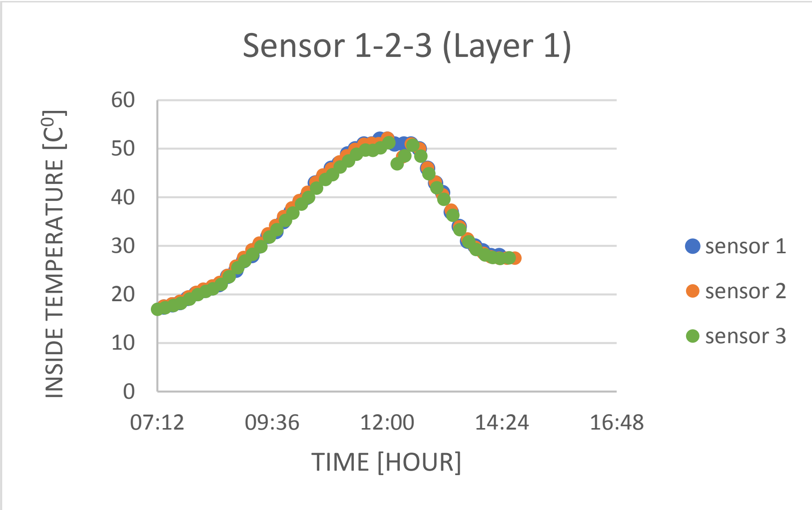

Fig. 4.9: Layer 1 of dryer has first three sensor-Inside Temperature-Time

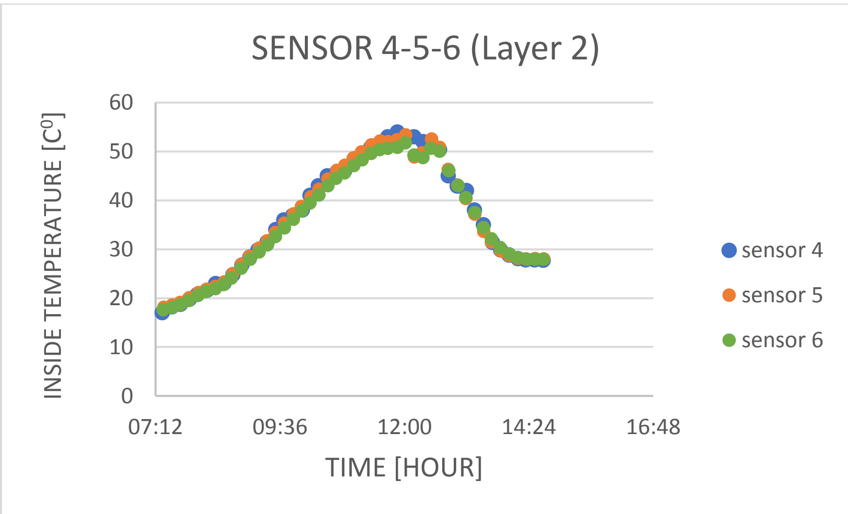

Fig. 4.10: Layer 2 of dryer has three sensors-Inside Temperature-Time

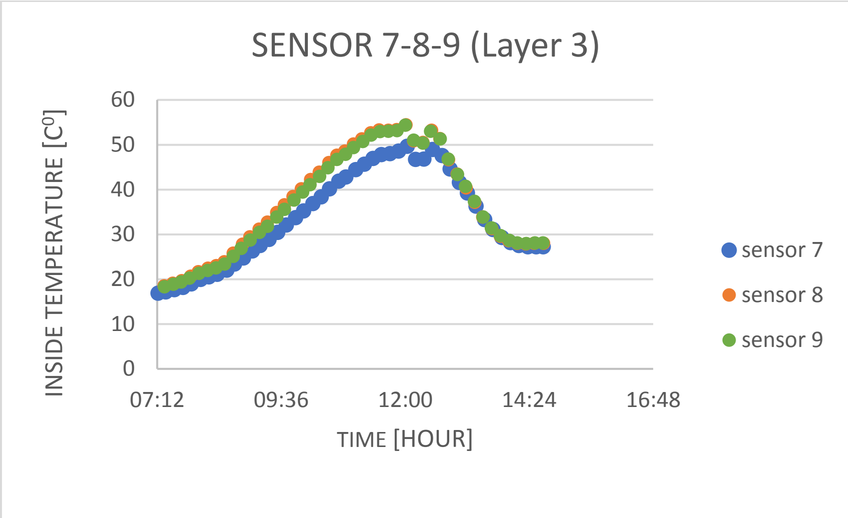

Fig. 4.11: Layer 3 of dryer has last three sensors-Inside Temperature-Time

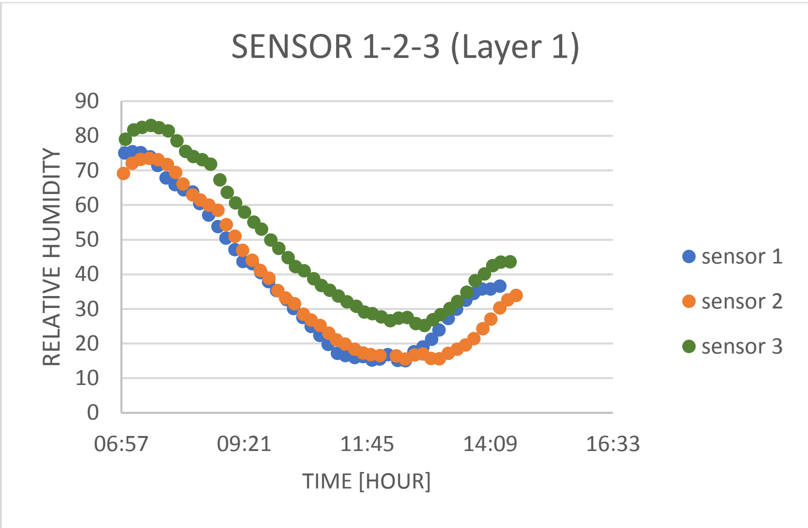

Fig. 4.12: Layer 1 of dryer has first three sensor-Relative Humidty-Time

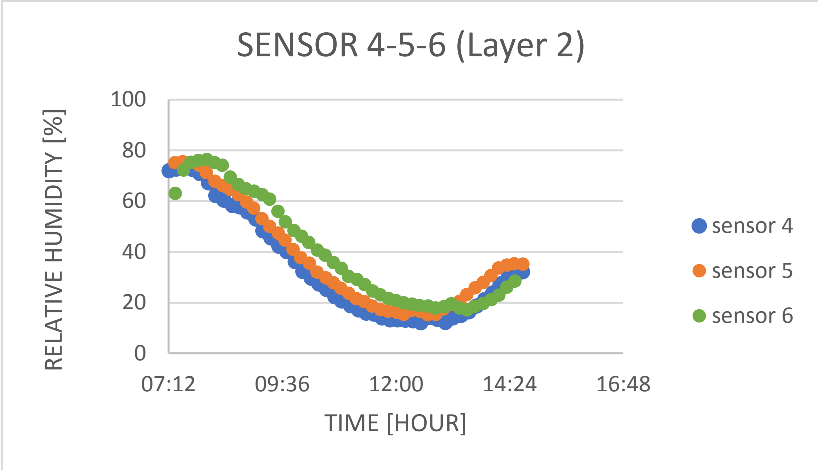

Fig. 4.13: Layer 2 of dryer has three sensors-Relative Humidity-Time

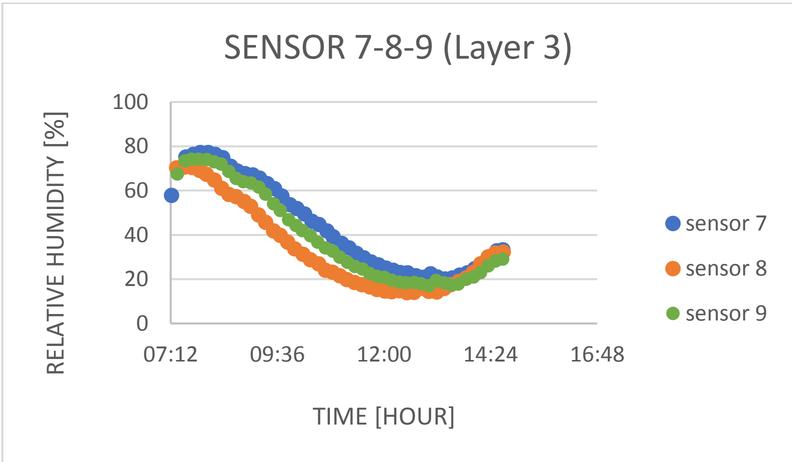

Fig. 4.14: Layer 3 of dryer has last three sensors Relative Humidity-Time

As seen in Figures there is no major difference for initial and final inside temperature and relative humudity values between the sensors in the same layers. To see the difference clearly, we can create bigger drying box with more layer and higher capacity. As the distance between the sensors increases, temperature difference might be more obvious. The 5 cm gap of second layer from the back wall provide a better air flow to dry each material group equally. In case of having more layers in the drying box, gaps from the wall of middle layers will help to complete the systems air flow distribution.

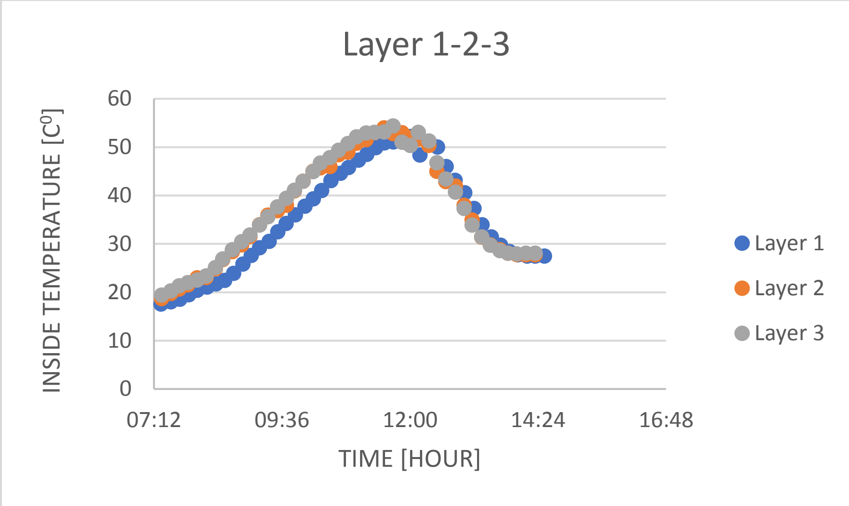

Fig. 4.15: Comparison of Inside Temperature Between Layers

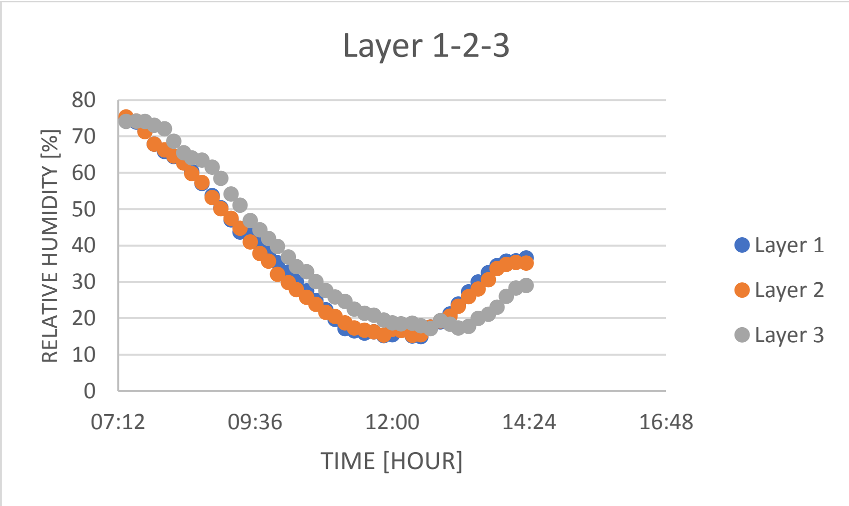

Fig. 4.16: Comparison of Relative Humidity Between Layers

When we make a graph comparing the layers with each other, we notice that Layer 1 as bottom level reaching the certain amount of heat sooner than the others. The main reason might be suggested as the location of this layer which has the closest spot to the hot air flow inlet. Furthermore, Layer 1 seems to reduce the relative humidity sooner, consistent to temperature difference. The humidity change at the end of Figures may refer to waiting time of material inside the drying box after they reach the maximum moisture lost in 4 hours from start.

4.3.2 Oven drying

Oven drying is the second selected method for drying biomass. It is used to remove water and other solvents from the material inside. The ovens remove moisture through a convection process, collecting it elsewhere so the object becomes dehydrated.

4.3.2.1 Design of Oven Drying System

The oven drying system that is used in the experiments is the brand of BINDER: FED 400 with capacity: 1000 mm width × 800 mm height × 500 mm depth as in Fig. 4.17. It has heating chambers with timing functions and a adjustable fan, temperature and convection conditions. Temperature range is between room temperature plus 5 °C to 300 °C .[43]

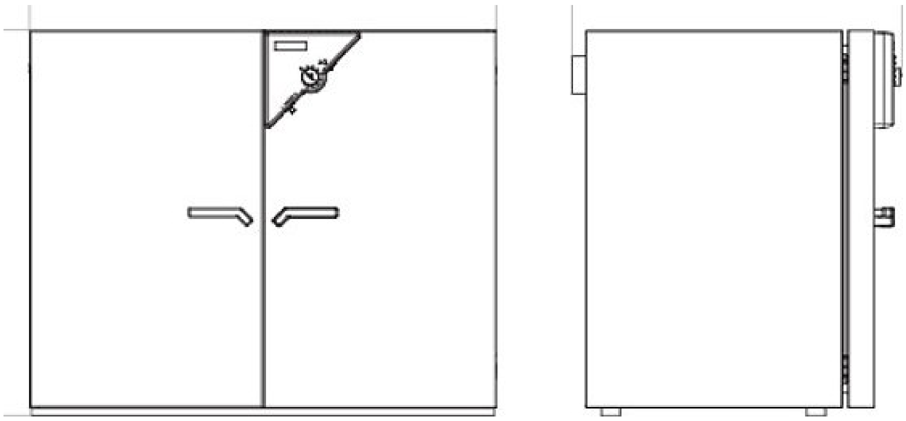

Fig. 4.17: Oven Sketch with Main Dimensions [43]

4.3.2.2 Experiment

The samples were chosen same to compare the results with solar drying system. They were dried by binder laboratory hating and drying oven at a drying temperature of 105 ˚C for 5 h with an air fan speed of 80%. The drying temperature of 105 ˚C was chosen together with five hours of drying time to efficiently evaluate the changes in the quality of the different samples during the drying process. The moisture reduction, weight reduction, and volume reduction of the samples were recorded at different times.

4.3.2.3 Results, Solution and Discussion to the Oven Drying Systems

The initial lower heating values and final lower heating values of the samples were approximately estimated based on the following Equations (10) and (11) :

$$LHV_{initial} = \sum_{i=1}^{n}\left(\frac{W_i}{D_{avg}} \times \frac{(100 - MC_i)}{100} \times E_i\right) \quad [\text{ MJ/kg }] \quad (10)$$

$$LHV_{final} = LHV_{initial} \times \frac{\sum_{j=1}^{n}\left(\frac{W_j}{D_{avg}} \times \frac{(100-MC_j)}{100}\right)}{\sum_{i=1}^{n}\left(\frac{W_i}{D_{avg}} \times \frac{(100-MC_i)}{100}\right)} \quad [\text{ MJ/kg }] \quad (11)$$

where

$LHV_{initial}$ and LHV_{final} are the initial lower heating values and final lower heating values of the samples [MJ/kg]. In formula D_{avg} is the average dry mass of the biodegradable wastes in mass [kg] (assumed as 0,2 kg, based on the fact that the total weight and the moisture content of the biodegradable wastes are 1 kg and 80 %, respectivelyW_i is the initial weight of a waste component i in the total initial weight of the waste composition [kg]. W_j is the final weight of a waste component j in the total final weight of the waste composition [kg]. M_{C_i} and M_{C_j} are the initial and final moisture content of the waste component i and j [%]. E_i is the energy content of a waste component i [MJ/kg]. n is the total number of the waste types in the total waste composition. The energy contents of food wastes and green leaves are in the range of 3489 – 6979 MJ/kg and 2326–18,608 MJ/kg, respectively.[39] The average energy content and moisture content of the biodegradable waste samples were approximately considered as 3.5 MJ/kg and 80 % [39], respectively, for ease of estimation.

Table 4.4: Properties of the biodegradable waste samples before and after drying at 105 ◦C for 5 h. [39]

Sample No.	Initial Mass (g)	Final Mass (g)	Mass Reduction (%)	Initial Volume (10^{-6} m^3)	Final Volume (10^{-6} m^3)	Initial Moisture (%)	Final Moisture (%)	Initial LHV (MJ/kg)	Final LHV (MJ/kg)
1	500	110	78	1100	500	82.00	4.00	3.15	16.80
2	500	166	67	1800	1300	79.11	15.20	3.66	14.84
3	500	145	71	1850	1050	83.15	11.00	2.95	15.58
4	500	144	71	1550	1100	71.20	10.80	5.04	15.61
5	500	182	64	1700	1300	77.42	18.40	3.95	14.28
6	500	224	55	1300	900	84.73	26.80	2.67	12.81
7	500	250	50	2000	1800	81.96	32.00	3.16	11.90
8	500	157	69	1800	900	79.11	13.40	3.66	15.16
9	500	206	59	2350	1300	80.00	21.20	3.50	13.79

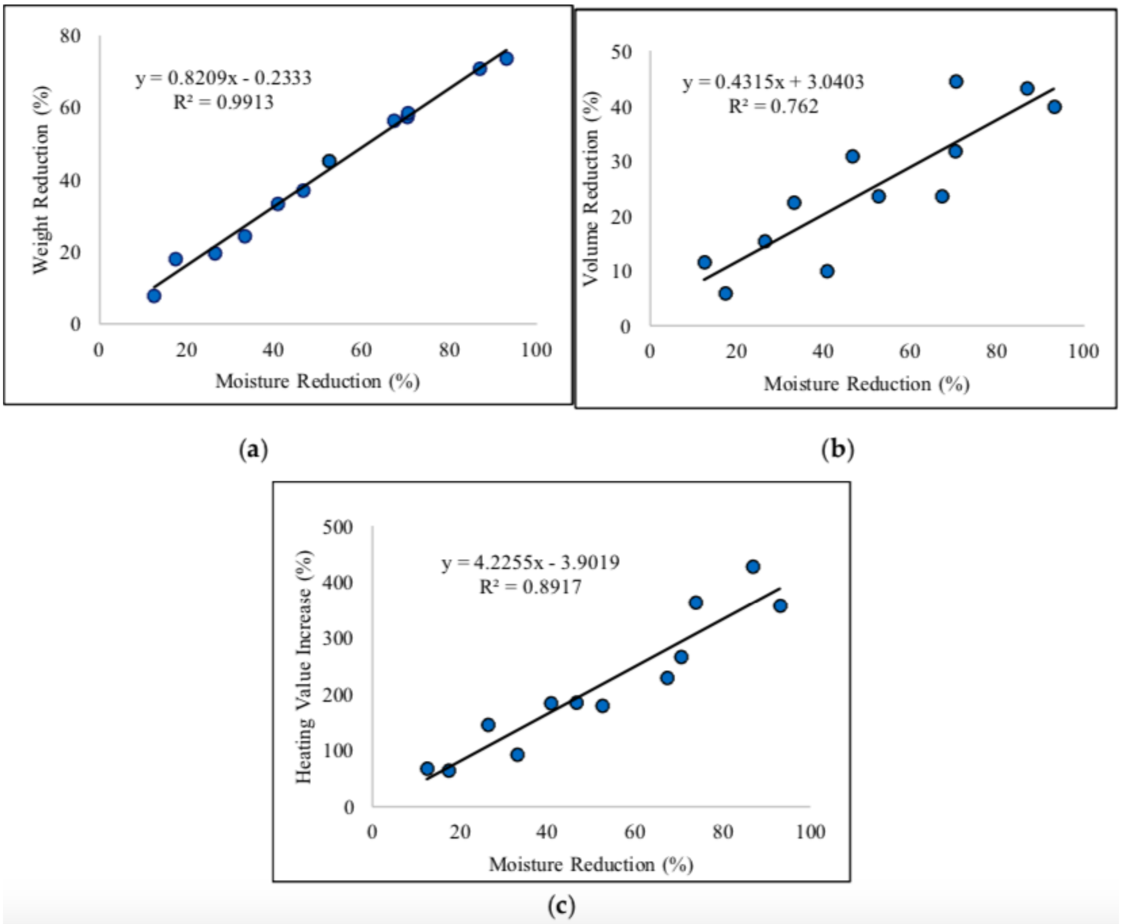

Fig. 4.18: Effect of moisture reduction on (a) weight reduction, (b) volume reduction, and (c) heating value increase of the biodegradable waste samples [39]

As seen in Table 4.4 and Fig. 4.18 the higher moisture content, the lower the calorific values, both derived from the relative decrease in the amount of material per unit mass of fuel, and because of the need to use some energy from the material to evaporate the water.

Increase Rate in Calorific Value =[%] (12)

Increase average rate in calorific value after oven drying : 220 %

4.4 Summary and Recommendations

This research presents a review of the designs, details of structure and operating values of solar drying system and oven drying system. To propose optimum drying solutions, parameters such as calorific value and moisture content were measured of selected biodegradable material.

Results shows effects of selected drying methods on biomass with advantage and disadvantage for each method. For conventional drying systems, drying efficiency increase with temperature, so promising drying at temperatures as high as the product can resist. However, for active solar dryers, the maximum tolerable temperature could not provide an optimal dryer design. In the design of indirect solar dryer would be work with high drying air temperatures and housing lower air-flow rates. The solar drying system can be optimized to give a higher value of air temperature and flow rate. The temperature and air flow rate increase as the length of the absorber increases. Besides, the width of the collector is inversely proportional to the outlet temperature and directly proportional to air flow rate. Flat plate solar collector can be tilted to achieve a highest solar irradiation absorbed. Materials that are used for insulation can be used to achieve higher resistance of heat transfer. Drying chamber design can also be modified to enhance the efficiency of the drying system, starting by coating the walls with black paint for higher solar radiation absorption or insulate them for less heat losses to the ambient. Solar drying system can only used during day time when satisfactory amount of solar energy is present. The proper regions to use the system is where the daytime is longer as in south part of Turkey. The system has less efficiency as compared with modern type of dryers. A reserve heating system is required for materials need constant drying.

In oven drying methods, the sample is heated under specified conditions. The amount of moisture determined is highly dependent on the type of oven used, conditions within the oven, and the time and temperature of drying. The method is simple, and the oven that is used for the experiments allows for drying of large numbers of samples. Based on the experiment result for nine samples, it is seen the reverse ratio between moisture inside materials and their calorific value as shown in Table 4.4. There is a significant improvement in calorific value and decrease in mass after drying materials. The moisture reduction results in weight reduction, volume reduction, and heating value increase of the biodegradable materials. After drying for material there are :

- Decrease in moisture about 50%
- Decrease in mass about 40%
- Reduce of volume of material about 25%
- Increase in calorific value about 220%

These conclusions are significant and beneficial in terms of storage, transport and handling of this type of material. For solar and oven dryer system, material is enclosed in the dryer and thus covered from dust, insects, birds and animals. The faster drying level decreases the risk of decomposition by microorganisms.

5. Conclusion

Biomass is one of renewable energy sources and refers to biological material derived from living organisms such as wood and waste. It is becoming very popular and getting worldwide acceptance day by day. The main purpose of this research is to examine biodegradable materials as energy sources and to use them effectively. Biodegradable materials are energy sources with relatively low calorific value. Drying these materials is the fundamental solution to increase it. There are various methods for drying as conventional and modern. In my thesis I researched for possible methods and did experiments with indirect solar drying sytem and drying oven. The reason that I chose these techniques is to combine renewable energy solutions by using solar system with biomass and compare the results with a more comman method of oven dryer.

One of the main reason for this research is Turkey, where the production of biodegradable material in MSW is more than 50% in touristical areas. These touristical places also have relatively high temperature during 7 months from April to end of October. Hotel complexes produce significant amount biodegradable waste such as food waste. In order to reduce desposing the wastes to landfill areas, decrease transport costs and use the waste to produce electricity and heat, I see a potential to use solar drying system in such countries.

By the result of research and experiments solar drying system needs no energy during day time, it is more beneficial to the small scale process which is lack of electricity or other fuel for drying. Consequently, the overview of low cost and localmade solar dryers delivers a encouraging alternative to decrease the big losses. The other selected method is oven dryer which needs constant electricity during drying process. It has more material capacity which makes it more proper for large scale processes. Drying ovens have wide range of temperature and air flow option which can adjusted by user. To be used in industrial processes, oven dryer seems more convenient. In both methods biodegradable materials were dried to decrase the moisture content around 50 % and obtained positive results for increased calorific value around 220 % .

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6.1 Applied results of the student

Utility Models

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